PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G05B 13/04	A1	(11) International Publication Number: WO 99/46646 (43) International Publication Date: 16 September 1999 (16.09.99)

(21) International Application Number: PCT/IL99/00119

(22) International Filing Date: 2 March 1999 (02.03.99)

(30) Priority Data:
123607 10 March 1998 (10.03.98) IL

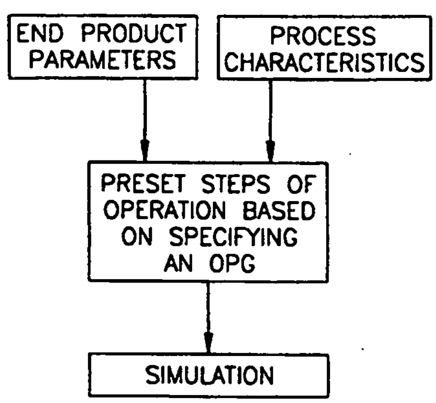
(71)(72) Applicant and Inventor: BERKOOZ, Oded [IL/IL]; Nili Street 8, 58279 Holon (IL).

(74) Agent: REINHOLD COHN AND PARTNERS; P.O. Box 4060, 61040 Tel Aviv (IL).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: OPTIMIZATION METHOD AND DEVICE



(57) Abstract

A method and a device for optimizing a process for manufacturing a certain end product with a certain system are presented. The end product is defined by certain desired conditions of its *N* parameters. The system is defined by certain desired conditions of its *M* parameters. The manufacturing process is defined by certain desired conditions of its *Q* working parameters. At least one of these *M* or *Q* parameters depends variably on at least another one of these *M* or *Q* parameters according to a predetermined mathematical model. Initially, a starting point and an optimum condition of the optimization are specified. The starting point is in the form of such an initial value of at least one of the *Q* or *M* parameters that each of corresponding initial values of the *N* parameters and of the other *M* and *Q* parameters satisfies the respective desired condition. The optimum condition is such that at least one of the desired conditions of the *N* parameters is satisfied. Then, simulation procedures are performed by changing the at least one initial specified value of the *Q* or *M* parameters, so as to cause changes of the initial value of at least one of the *N* parameters that defines the specified optimum condition. Concurrently, the mathematical model is operated for calculating current values of the *M* and *Q* parameters. The calculated current values are analyzed for adjusting at least one of them so as to satisfy the optimum condition.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece			**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**ML**	Mali	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MN**	Mongolia	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MR**	Mauritania	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MW**	Malawi	**US**	United States of America
CA	Canada	**IT**	Italy	**MX**	Mexico	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NE**	Niger	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NL**	Netherlands	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NO**	Norway	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**NZ**	New Zealand		
CM	Cameroon			**PL**	Poland		
CN	China	**KR**	Republic of Korea	**PT**	Portugal		
CU	Cuba	**KZ**	Kazakstan	**RO**	Romania		
CZ	Czech Republic	**LC**	Saint Lucia	**RU**	Russian Federation		
DE	Germany	**LI**	Liechtenstein	**SD**	Sudan		
DK	Denmark	**LK**	Sri Lanka	**SE**	Sweden		
EE	Estonia	**LR**	Liberia	**SG**	Singapore		

Optimization Method and Device

FIELD OF THE INVENTION

The present invention is in the field of optimization techniques and relates to a method and a device for designing an optimized process and/or associated processing system for manufacturing a certain product.

BACKGROUND OF THE INVENTION

Methods for designing a system and/or a process used for manufacturing a certain product are in great demand for a variety of industries, for example, chemical, biotechnological, food, cutting tools, microelectronics, electronics design, structure design, etc. The need for optimized technological processes is more essential when mass production of products is required.

Earlier methods of the kind specified are typically based on simulation procedures performing so-called 'trial-and-error' adjustments of earlier models, if any, laboratory data, or other complicated mathematical formulation or optimization procedures. The procedures based on laboratory data deal with significantly different parameters of the end product obtained in the laboratory than that expected to be manufactured by suitable mass production techniques or to be structured. To this end, teams of engineers are

involved in designing procedures and perform the optimization methods of earlier models. They can rely only on their experience and intuition for reaching a "right design" or use complicated mathematical formulation or optimization procedures, their experience and intuition being based solely on the engineers' knowledge of the existing processes and devices.

Fig. 1 illustrates a block diagram showing the main principles of such a conventional method for designing a "supposedly optimized" process and/or device to be used for manufacturing a certain product. Data required for performing the design, so-called "reference data", is representative of the following particulars:

(1) the parameters of an end product to be manufactured, prepared or built;

(2) the parameters of existing manufacturing or preparation processes and/or devices of the kind, i.e. for manufacturing a similar product;

(3) 'working' conditions of the manufacturing process, if known; and

(4) design rule features.

The term *"working conditions"* used herein signifies those conditions inside the processing device or environment which affect the end product parameters and should be maintained within predetermined ranges during the process.

The above data is analyzed by the engineers so as to perform numerous simulation procedures for estimating, based solely on their capabilities and intuition, the optimized parameters of a designed apparatus or environment. However, such a method lacks any effective leverage and vital assistance of the engineers capable of creating new concepts and ideas, beyond the engineers' capabilities and intuition. This results in wasted efforts, longer time consumption, higher costs of experiments and sometimes even leads the design to a dead end after having all the expenditures.

Methods and systems for optimizing technological processes have recently been developed, being based on a common feature of specifying a so-called "objective function" which should be minimized or maximized under defined conditions. However, these minimized or maximized values of the objective function depend on a way of selecting a point for starting the search and, therefore, represent local minimum or maximum of the objective function and not the global value. Again, the knowledge and experience of engineers are required for determining either the global minimum/maximum of a specified objective function from a plurality of local minimums/ maximums, or an optimal solution for positioning a search starting point.

U.S. Patent No. 5,587,897 discloses an optimization method and device for determining an optimal solution by means of detecting a search start point for starting the search of the optimal solution. More specifically, objective function, search region and required precision are set. Then, the objective function is made into a convex function and its maximum value is detected using a local search method. However, this approach brings to complex objective functions or procedures, as well as to the need for an experienced engineer who would combine his knowledge of the process to be optimized with his deep knowledge of the optimization mathematics and procedures.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome the above listed and other disadvantages of the conventional approach and provide a novel method and device for optimizing a process and/or a processing apparatus used for manufacturing a certain product.

There is thus provided according to one aspect of the present invention a method for optimizing a process for manufacturing a certain end product within a system, wherein the end product is defined by certain desired

conditions of its N parameters, the system is defined by certain desired conditions of its M parameters and the manufacturing process is defined by certain desired conditions of its Q working parameters, such that at least one of said M or Q parameters depends variably on at least another one of said M or Q parameters according to a predetermined mathematical model, the method comprising the steps of:

(a) specifying a starting point in the form of such an initial value of at least one of said Q or M parameters that each of corresponding initial values of said N parameters and of the other M and Q parameters satisfies the respective desired condition;

(b) specifying an optimum condition under which at least one of said desired conditions of the N parameters is satisfied;

(c) providing simulation procedures by changing said at least one initial specified value of the Q or M parameters so as to cause changes of the initial value of at least one of the N parameters that defines said optimum condition and concurrently operating said mathematical model for calculating current values of the M and Q parameters;

(d) analyzing the calculated current values for adjusting at least one of them so as to satisfy said optimum condition.

The term *"process for manufacturing"* used herein signifies a technological or scientific process, structure, effect or the like for producing or preparing a certain product, wherein the term *"product"* signifies a desired result of a process, structure or effect. The term *"system"* used herein signifies a specific environment, which may include an apparatus. The parameter(s) depending variably on the another parameter(s), as well as the another parameter(s), may be representative of process or system, or both of them.

The concept of the invention is based on the idea that an optimization

procedure, aimed at optimizing a manufacturing or preparation process and/or an associated system, always has certain goals. These goals are typically in the form of desired values (or ranges of values) of the parameters of end product, process and/or processing system. To this end, a starting point of the optimization method is specified in the form of a certain initial condition of at least one parameter of either the system or process, under which all the product parameters and the other process and system parameters satisfy their desired conditions. The initial condition is in the form of a certain value (or range of values) of at least one process or system parameter. This value is specified in accordance with symmetry and/or order of magnitudes considerations that may not be achievable in reality. Hence, the starting point of the optimization method represents such a condition of at least one of the system or process parameters, under which the goals of the optimization procedure related to all the other parameters are supposed to be satisfied.

At least one of the goals of the optimization procedure, a so-called "optimization goals condition" (OPG), is selected so as to define an optimum condition of the optimization method to which the current results of the optimization are compared. The OPG may be representative of at least one of the desired conditions of the end product. Additionally, it may also be representative of at least one of the desired process conditions. It will be readily understood that the optimum condition is satisfied at the starting point of the optimization method.

It is thus evident that objective functions of the conventional approach are replaced here by OPG in the form of the desired condition of at least one of the end product parameters. This parameter represents real and measurable data used as reference data to which the current results of the optimization method are compared. Owing to the fact that the starting point of the optimization procedure may include values that are not feasible, such an optimization procedure strives for appropriate feasible values that can be

realized while being compared to the OPG values.

The concept of the invention is simple and easy to understand. Mathematical tools used for the optimization procedure according to the invention can be chosen by engineers involved in a certain manufacturing or preparation process to be optimized, or by engineers involved in the optimization procedure. Such engineers may input their experience and intuition and the optimization method can leverage creativity, or may apply any known mathematical routines within their personal skills. One of the advantages of the invention is that the optimization procedure brings-up directly to a design engineer the "feel", behavior and insight into the systems and processes to be optimized without complex action of the mathematical functions.

More specifically, the idea of the present invention is based on that the system and/or process to be optimized are defined by N parameters of the end product, M parameters of the system and Q parameters of the process which depend variably on each other. The whole reference data one should have in his/her disposal in order to perform the optimization method includes the following:

- desired values of the end product parameters;
- desired or at least feasible values of the system' and/or process' parameters; and
- mathematical model representing the relationship between the product, process system parameters and design-rules.

The minimum requirements for carrying out the optimization method are as follows:

- a processor equipped by memory for storing the above reference data and by input and output interfaces; and
- suitable software for operating the processor so as to conduct simulation procedures based on the mathematical model.

Thus, in order to start the optimization procedure, at least one of the end product desired conditions should be selected to specify OPG, and such an initial condition of the optimization method should be set, under which the end product and other process and system desired conditions are satisfied.

The initial condition may be represented by the value(s) of at least one of the ***M*** parameters and/or at least one of the ***Q*** parameters which is defined by symmetry, order of magnitude and/or other engineering or scientific considerations that may not be achievable in reality. For example, the initial condition is defined by an infinite value of one of the system's parameters. In this case, the simulation procedure begins with reducing this initial value. The process or system parameter which should be adjusted is detected by means of determining and analyzing the behavior, for example, gradients of that at least one product's parameter which defines the optimum condition, depending on each of the changes of the process and/or system parameters.

The above optimization method may be applied to any product manufactured by a process, structure or effect that can be defined by specific mathematical, scientific or statistical relations between the product, process (structure, effect) and system for its manufacturing. For example, a chemical vapor deposition (CVD), or other physical, chemical, biochemical electrochemical, electromagnetic, etc. processes may be optimized by this method.

According to another aspect of the present invention there is provided a device for optimizing a process for manufacturing a certain end product within a system, wherein the end product is defined by certain desired conditions of its *N* parameters, the system is defined by certain desired conditions of its ***M*** parameters and the manufacturing process is defined by certain desired conditions of its ***Q*** working parameters, so that at least one of said ***M*** or ***Q*** parameters depends variably on at least another one of said ***M*** or ***Q*** parameters according to a predetermined mathematical model, the device

comprising:

i. a memory for storing reference data which is generated by an operator and is representative of said desired conditions of *N*, *M* and *Q* parameters, predetermined mathematical model, and an optimum condition and a starting point of the optimization procedure,, the starting point being in the form of such an initial value of at least one of said *Q* or *M* parameters that each of corresponding initial values of said *N* parameters and of the other *M* and *Q* parameters satisfies the respective desired condition, the optimum condition being such that at least one of said desired conditions of the *N* parameters is satisfied;

ii. input interface coupled to said memory for inputting said reference data and said data generated by the operator;

iii. a processing unit interconnected between said memory and input interface for performing said simulation procedure and producing data indicative of simulation results; and

iv. an output interface for displaying said produced data indicative of the simulation results.

According to yet another aspects of the present invention there are provided a method and a device for optimizing a system used in a manufacturing process for manufacturing a certain end product.

More specifically the present invention is used for designing an apparatus employed in a CVD manufacturing process and is therefore described below with respect to this application.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how the same may be carried out in practice, several preferred embodiments will now be described, by way of example only, with reference to the accompanying drawings, in

which:

Fig. 1 is a schematic block diagram illustrating the main principles of a conventional optimization method of the kind specified;

Fig. 2 is a schematic block diagram illustrating the main principles of an optimization method according to the invention;

Fig. 3 is a schematic illustration of the main components of a system for manufacturing a product within a processing apparatus, which process and apparatus has to be optimized; and

Figs. 4a and 4b illustrate a flow diagram of the main steps of a method for optimizing the process and apparatus used in the system of Fig. 3.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 illustrates the main principles of a conventional approach for optimizing a processing apparatus used for manufacturing a certain product. As shown, this approach is based on the existing models of an apparatus of the kind and employs the capability and intuition of designers to compile the data manually, or by using design-rules and objective function of the earlier kind, for performing numerous simulation and trial-and-error procedures.

Reference is now made to Fig. 2, illustrating the main principles of a new approach according to the invention. The illustration is similar to that of Fig. 1, in order to facilitate the understanding of essential features of the present invention. Total reference data, required for performing the design, includes solely the end product's parameters, working conditions of the process and design-rules. The other reference data representative, for example, of existing models' parameters, may help but is not necessary. Additionally, engineers' capability and intuition are replaced here by a certain sequence of steps, which should be performed prior to and concurrently with the simulation, and on which the simulation procedures are based. Similarly, the engineers' capability and intuition may help but are not necessary. The

term *"OPG"* or *"optimization goals condition"* signifies the results' criteria of the design, which should be specified and on which the sequence of steps is based. The principles and purposes of OPG will be described more specifically further below.

In order to illustrate more specifically the main principles of the invention, the following example of optimizing a process and apparatus for manufacturing a certain product will now be described with reference to Figs. 3 and 4a-4b. Fig. 3 illustrates a system **10** for chemical vapor deposition of silicon on a silicon wafer **12** within a reactor **14**. The reactor **14** is in the form of a cylinder having its diameter D_0 and height h. The reactor **14** is provided with inlet, top and outlet, bottom openings **16a** and **16b** having diameters D_1 and D_2, respectively. The wafer **12** is supported on a susceptor **18** appropriately accommodated inside the reactor **14** and is coupled to a heating element **20** so as to be heated up to a desired temperature $T°$. A stream of a reactant gas SiH_4 is supplied under a certain pressure into the reactor **14** through the opening **16a**.

As a result of a chemical process of decomposition of SiH_4, that is:

$$SiH_4 \rightarrow Si + 2H_2$$

the silicon atoms continuously precipitate on a heated surface **12a** of the wafer **12**, while the hydrogen is exhausted through the outlet opening **16b** (together with other undesirable products). The above process of silicon deposition on wafers is known *per se* and, therefore, need not be described in more detail.

The end product, i.e. the silicon deposition on the wafer **12**, can be characterized by the following main parameters:

(N_1) thickness A of the silicon deposition on the wafer;

(N_2) substantially homogeneous distribution of the silicon atoms on the wafer, or a so-called "flatness criterion factor", such that the flatness of the silicon A_f is of a desired value $A_f^{(0)}$.

The CVD process is characterized by the following main working conditions:

(Q_1) temperature $T°$ of the wafer's surface **12a** should satisfy the following condition:

$$550°C \leq T° \leq 555°C$$

(Q_2) the pressure P inside the reactor **14** should be within the following range: 0.9 Atm - 1.1 Atm;

What has actually to be designed is the structure of the reactor **14**, which is characterized by the following parameters:

(M_1) the exact shape and geometry of the reactor, including its diameter D_0 and height h;

(M_2) top inlet diameter D_1;

(M_3) bottom outlet diameter D_2;

(M_4) materials MT_i of the reactor (aluminum, copper, stainless steel, etc.) including their engineering parameters such as, for example, heat capacity and thermal conductivity;

(M_5) gas inlet and outlet pressures P_1 and P_2 and temperature T_1 and T_2, respectively;

(M_6) resistance R and current I of the heating element **20**.

The above parameters N_1-N_2, Q_1-Q_2 and M_1-M_6 of the product, process and apparatus actually define the total goals of the optimization method.

As indicated above, the working conditions of the process are those affecting the end product parameters. It is appreciated that the above conditions Q_1 and Q_2 of the process vary during the manufacturing process according to the following partial differential equations (constituting a mathematical model):

(1) "Continuity Equation" relating to the gas behavior inside the reactor

$$\frac{\partial \rho}{\partial t} + \nabla^{\bullet}(\rho V) = 0$$

wherein ρ is the gas density (of the ideal gas);

V is the gas velocity vector;

(2) "Momentum Equation"

$$\rho(\frac{\partial V}{\partial t} + V^{\bullet}\nabla V) + \nabla \rho = \mu(\Delta V + \frac{1}{3}\nabla(\nabla^{\bullet}V) - \rho g$$

wherein μ is the gas viscosity;

(3) "Energy Equation"

$$\rho C_{\rho}(\frac{\partial T}{\partial t} + V^{\bullet}\nabla T) + \rho\nabla^{\bullet}V = \nabla^{\bullet}(\kappa\nabla T)$$

wherein C_{ρ} is the gas heat capacity;

κ is the gas thermal conductivity

(5) definitions of the appropriate boundary conditions;

(6) amount of heat supplied to the wafer and vicinity due to the heater;

and according to the characteristic behavior of the growth of the silicon particles:

(6) "Growth Rate"

$$G_R = C_0(R_c, X_w, Y_w, Z_w) * \exp(-\frac{E_a}{kT})$$

wherein G_R is a current growth rate;

$C_0(R_c, X_w, Y_w, Z_w)$ is a coefficient relating to the reactant gas SiH_4 and the wafer surface points;

R_c is a concentration of the reactant gas SiH_4 in a

vicinity of the surface of the wafer;

X_w, Y_w, Z_w are space coordinates of the wafer's surface;

E_a is the activation energy.

One of the essential features of the present invention consists of specifying an "optimization goals condition" (OPG) defining the results' criteria of the design. The OPG represents a specific condition of at least one parameter of the end product. In other words, the OPG may simply include the desired value (or range of values) of one of the product parameters, for example N_2, that is:

$$A_f = A_f^{(0)}$$

Generally, OPG is specified in accordance with the requirements of a manufacturer so as to be one of the real goals of the manufacturing process and/or indicative of the effectiveness of the manufacturing process. It will be readily understood that OPG may represent specific conditions of more than one of the end product parameters and one or more process conditions.

Another essential feature of the present invention is the provision of a starting point of the optimization procedure, which represents a so-called "ideal condition", under which the goals of the optimization method are substantially achieved. More specifically, the ideal condition provides such a value of at least one of the process or apparatus parameters, that all the other product, process and apparatus conditions are satisfied. According to the present example, the initial condition is in the form of infinite dimension of the reactor **14**, that is:

$$D_0 \to \infty$$

$$h \to \infty$$

The above expressions together define the start point for performing the whole method of designing the optimized reactor **14**.

Generally, the ideal condition is in the form of such a value of at least

one of the reactor or process parameters which is defined by an order of magnitude and/or symmetry considerations, even as a so-called "wishful" condition that may not be achievable in reality. Alternatively and additionally, although not specifically exemplified, the ideal condition may be in the form of such a reactor's parameter that is defined by the consideration of symmetry. In other words, the reactor is such that the process' conditions thereinside are symmetrical relative to the end product.

It is also appreciated that each of the parameters included in the OPG depends variably, either directly or indirectly, on at least some of the other parameters related to the reactor **14**, process and product. According to the present example, the OPG defining parameter of the product N_2 is a function of all the above listed parameters as follows:

$$N_2(N_1, Q_1, Q_2, M_1, M_2, M_3, M_4, M_5, M_6, M_7)$$

or more specifically:

$$A_f(D_0, h, D_1, D_2, M_i, T, T_1, T_2, P, P_1, P_1, R, I, X_w, Y_w, Z_w, A)$$

The method of optimizing such an apparatus used in CVD manufacturing process will now be described with reference to Figs. 4a-4b. Initially, the OPG is selected (step 22), for example, as described above. Then, the start point in the form of the ideal condition is specified (step 24), for example, by assuming that the reactor **14** is of infinite dimensions. An initial simulation procedure begins (step 26) with changing (reducing) these dimensions (step 27) and proceeds with calculating current values of the OPG defining parameter, i.e. N_2 (step 28). These current values correspond to the changed, reduced values of the reactor's parameters $\boldsymbol{D_0}$ and $\boldsymbol{h}$.

Upon detecting that the OPG has changed (step 29), all the relevant parameters, namely those related to the end product, manufacturing process and reactor, generally designated ***PR*** (17 parameters $\boldsymbol{PR_1}$, ... , $\boldsymbol{PR_{17}}$ in the present example) are calculated (step 30) using the above equations. It should be noted that if OPG represents the desired range of values of the parameter

N_2, then this parameter is considered to be changed when its value is out of the desired range.

The steps 26, 27, 28, 29 and 30 are sequentially repeated until changes in at least some of the parameters $\boldsymbol{PR_1}, \ldots, \boldsymbol{PR_{17}}$, for example $\boldsymbol{i}$ parameters, are detected (step 32). These changes are caused by the act of reducing the dimensions of the reactor **14**.

The above data is analyzed so as to determine that/those parameter(s) whose change(s) affect(s) significantly, in comparison to the others, the changes of the OPG. To this end, the gradients of the OPG depending on the changes of each of the detected parameters are separately determined (step 34), that is:

$$dN_2/dPR_1, \ldots., dN_2/dPR_{i-1}, dN_2/dPR_i$$

At least one of those detected parameters is changed accordingly (step 35). The detected parameters or those previously changed so as to cause the changes of these detected parameters are adjusted (step 36) in order to maintain the "ideal condition" as specified above. It is appreciated that this adjustment procedure is followed by continuously repeating the steps 26-36.

Upon detecting that the OPG is maintained, i.e. the flatness A_f of the silicon is of the desired value $A_f^{(0)}$ (step 38), current parameters of the reactor **14** ($\boldsymbol{M_1}$-$\boldsymbol{M_6}$) and working conditions of the process ($\boldsymbol{Q_1}$-$\boldsymbol{Q_2}$), which correspond to the current "ideal" value of the product parameter N_2, are analyzed (step 40). If the current parameters are found to be of the desired values (step 42), the design is completed. It should be noted that the desired values may be feasible values (or range of values) suitable for the specific manufacturing process. If the current parameters are found to be out of the desired range of values , the design is performed again starting from the step 26. It is understood that now the reactor's dimensions will be either reduced or increased depending on those current values previously received.

It is appreciated that all the above operational steps are carried out by a

processor operated by suitable software, based on the mathematical model capable of solving the above equations and analyzing the received solutions. The processor includes a memory for storing reference data representative of all the relevant parameters and the mathematical equations to be solved. Appropriate input and output interfaces are provided and coupled to or incorporated with the processor for, respectively, inputting the reference and other relevant data and indicating the calculated values and the design's results. Such processor and software may be of any known kind and do not form a part of the present invention.

Advantages of the method according to the invention are thus evident. Indeed, the optimization procedure starts from such a scientific "ideal" initial point, at which the specific conditions representing the goals of the optimization procedure are substantially satisfied. One of these goals (OPG) is selected to represent the final result's criteria of the optimization procedure to which the current results are compared. In other words, the optimization procedure begins from such a start point when the desired conditions are substantially satisfied and proceeds so as to maintain the OPG condition, rather than start with an undesirable condition and try to reach a specific desired one. Additionally, the desired condition to be maintained or OPG, on the one hand, is in the form of a certain measurable parameter and, on the other hand, represents a certain goal of a certain manufacturer aimed at increasing the effectiveness of the manufacturing process. Therefore, specifying this measurable parameter to be maintained which has a physical sense of an optimum condition for a specific technological process, enables to make the design physically realizable.

Those skilled in the art will readily appreciate that various modifications and changes may be applied to the preferred embodiment of the invention as hereinbefore exemplified without departing from its scope as defined in and by the appended claims. In the method claims that follow

characters, which are used to designate claim steps, are provided for convenience only and do not apply any particular order of performing the steps.

CLAIMS:

1. A method for optimizing a process for manufacturing a certain end product within a system, wherein the end product is defined by certain desired conditions of its N parameters, the system is defined by certain desired conditions of its M parameters and the manufacturing process is defined by certain desired conditions of its Q working parameters, such that at least one of said M or Q parameters depends variably on at least another one of said M or Q parameters according to a predetermined mathematical model, the method comprising the steps of:

   a) specifying a starting point in the form of such an initial value of at least one of said Q or M parameters that each of corresponding initial values of said N parameters and of the other M and Q parameters satisfies the respective desired condition;

   b) specifying an optimum condition under which at least one of said desired conditions of the N parameters is satisfied;

   c) providing simulation procedures by changing said at least one initial specified value of the Q or M parameters so as to cause changes of the initial value of at least one of the N parameters that defines said optimum condition and concurrently operating said mathematical model for calculating current values of the M and Q parameters;

   d) analyzing the calculated current values for adjusting at least one of them so as to satisfy said optimum condition.

2. The method according to Claim 1, wherein the desired condition of each of said Q parameters is in the form of a range of feasible values.

3. The method according to Claim 1, wherein the desired condition of each of said M parameters is in the form of a range of feasible values.

4. The method according to Claim 1, wherein the initial condition represents such a value of at least one of the M or Q parameters that is

defined by a symmetry considerations.

5. The method according to Claim 1, wherein the initial condition represents such a value of at least one of the ***M*** or ***Q*** parameters that is defined by an order of magnitude considerations.

6. The method according to Claim 1, wherein the initial condition is defined by an infinite value of at least one of the ***M*** parameters of the system.

7. The method according to Claim 1, wherein the initial condition is defined by scientific and technological considerations.

8. The method according to Claim 1, wherein the step of analyzing the calculated current values comprises:

determining the changed values of said at least one of the *N* parameters depending on the changes of said ***M*** and ***Q*** parameters, so as to detect at least one of the changed ***M*** and ***Q*** parameters that has to be adjusted, the at least one detected value corresponding to the greatest changed value of said at least one of the *N* parameters in comparison to the other determined changed values.

9. The method according to Claim 6, wherein the simulation procedure includes reducing said initial value of at least one of the ***M*** parameters.

10. The method according to Claim 1, wherein the process to be optimized is a chemical process

11. The method according to Claim 1, wherein the process to be optimized is a biochemical process.

12. The method according to Claim 1, wherein the process to be optimized is an electromechanical or electromagnetic process.

13. A method for optimizing a system used in a manufacturing process for manufacturing a certain end product, wherein the end product is defined by certain desired conditions of its *N* parameters, the system is defined by certain desired conditions of its ***M*** parameters and the

manufacturing process is defined by certain desired conditions of its Q working parameters, such that at least one of said M or Q parameters depends variably on at least another one of said M or Q parameters according to a predetermined mathematical model, the method comprising the steps of:

(1) specifying a starting point in the form of such an initial value of at least one of said Q or M parameters that each of corresponding initial values of said N parameters and of the other M and Q parameters satisfies the respective desired condition;

(2) specifying an optimum condition under which at least one of said desired conditions of the N parameters is satisfied;

(3) providing simulation procedures by changing said at least one initial specified value of the Q or M parameters so as to cause changes of the initial value of at least one of the N parameters that defines said optimum condition and concurrently operating said mathematical model for calculating current values of the M and Q parameters;

(4) analyzing the calculated current values for adjusting at least one of them so as to satisfy said optimum condition.

14. A device for optimizing a process for manufacturing a certain end product within a system, wherein the end product is defined by certain desired conditions of its N parameters, the system is defined by certain desired conditions of its M parameters and the manufacturing process is defined by certain desired conditions of its Q working parameters, such that at least one of said M or Q parameters depends variably on at least another one of said M or Q parameters according to a predetermined mathematical model, the device comprising:

i. a memory for storing reference data which is generated by an operator and is representative of said desired conditions of N, M and Q parameters, predetermined mathematical model and an

optimum condition and a starting point of the optimization procedure, the starting point being in the form of such an initial value of at least one of said Q or M parameters that each of corresponding initial values of said N parameters and of the other M and Q parameters satisfies the respective desired condition, the optimum condition being such that at least one of said desired conditions of the N parameters is satisfied;

ii. input interface coupled to said memory for inputting said reference data and said data generated by the operator;

iii. a processing unit interconnected between said memory and input interface for performing said simulation procedure and producing data indicative of simulation results; and

iv. an output interface for displaying said produced data indicative of the simulation results.

15. The device according to Claim 14, wherein said desired result of the simulation procedure is in the form of at least one of said desired conditions of the product such that at least one of said N parameters is within its desired range of values.

16. The device according to Claim 14, wherein said starting point is in the form of an initial value of at least one of said Q or M parameters such that corresponding initial values of said N parameters and of the other M and Q parameters satisfy their corresponding desired conditions.

17. A device for optimizing a system used in a manufacturing process for manufacturing a certain end product, wherein the end product is defined by certain desired conditions of its N parameters, the system is defined by certain desired conditions of its M parameters and the manufacturing process is defined by certain desired conditions of its Q working parameters, such that at least one of said M or Q parameters depends variably on at least another one of said M or Q parameters according to a predetermined mathematical

model, the device comprising:

a memory for storing reference data which is generated by an operator and is representative of said conditions of N, M and Q parameters, predetermined mathematical model and an optimum condition and a starting point of the optimization procedure, the starting point being in the form of such an initial value of at least one of said Q or M parameters that each of corresponding initial values of said N parameters and of the other M and Q parameters satisfies the respective desired condition, the optimum condition being such that at least one of said desired conditions of the N parameters is satisfied;

input interface coupled to said memory for inputting said reference data and said data generated by the operator;

a processing unit interconnected between said memory and input interface for performing said simulation procedure and producing data indicative of simulation results; and

an output interface for displaying said produced data indicative of the simulation results.

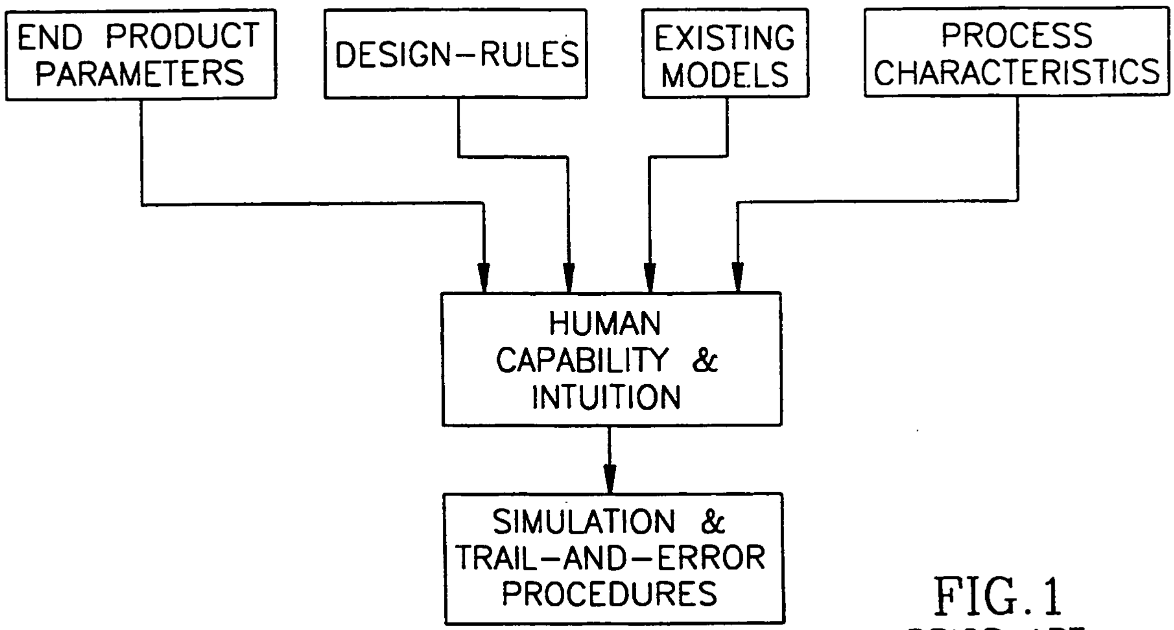


FIG.1
PRIOR ART

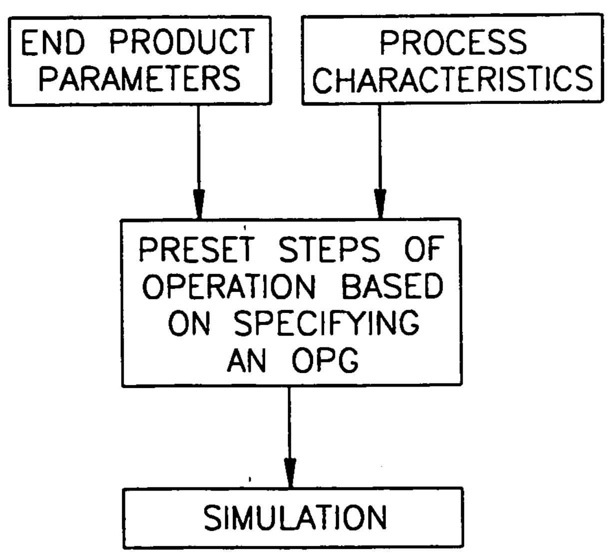


FIG.2

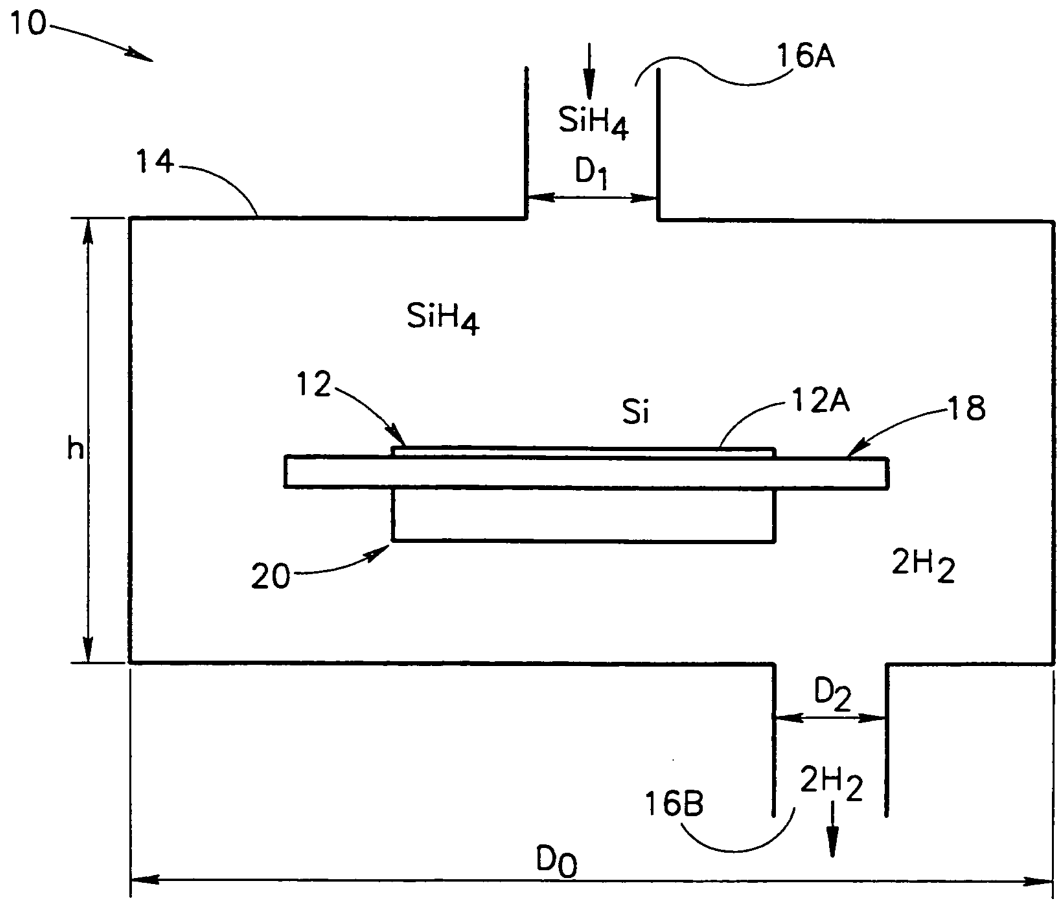
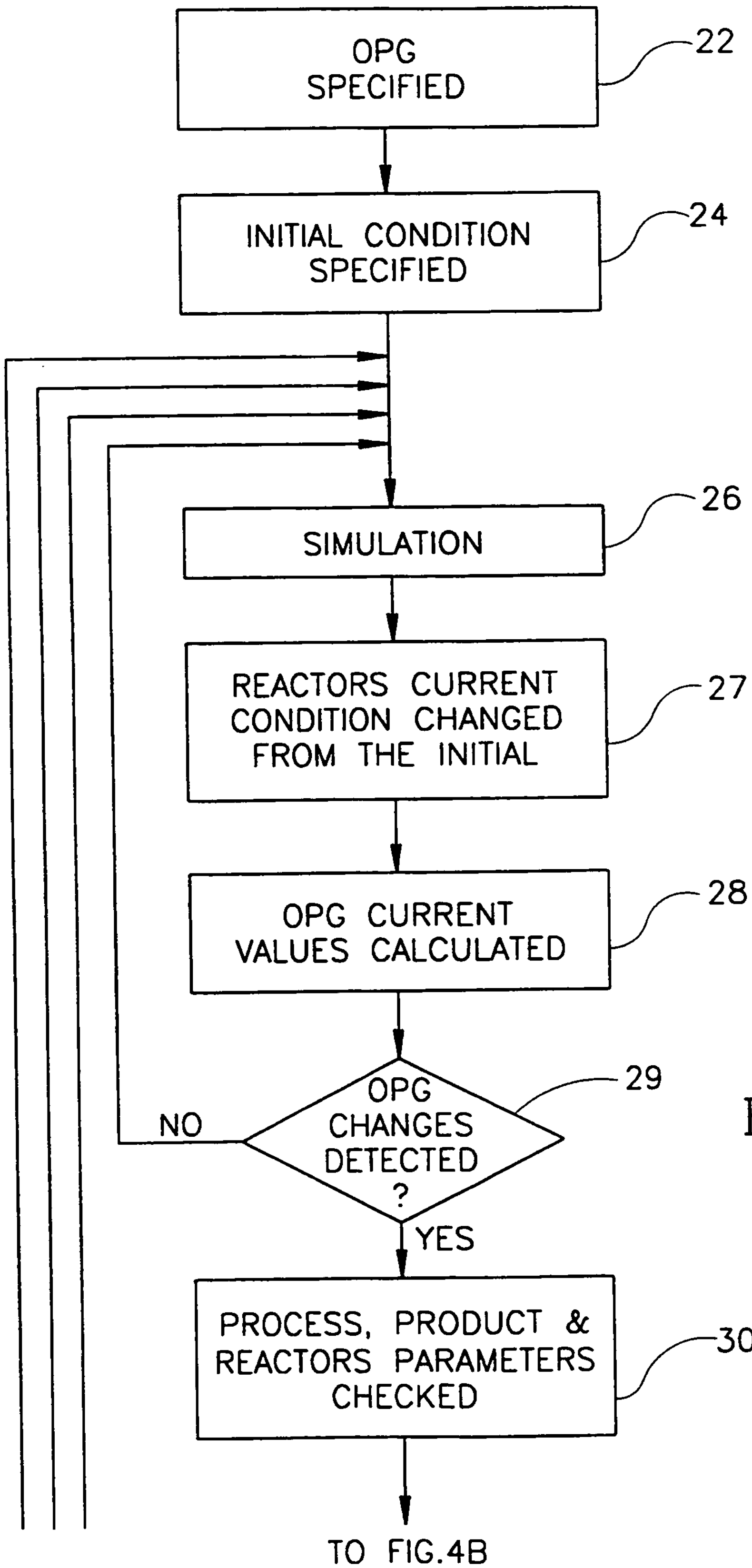


FIG.3



OPG SPECIFIED
22
INITIAL CONDITION SPECIFIED
24
SIMULATION
26
REACTORS CURRENT CONDITION CHANGED FROM THE INITIAL
27
OPG CURRENT VALUES CALCULATED
28
OPG CHANGES DETECTED ?
29
NO
YES
PROCESS, PRODUCT & REACTORS PARAMETERS CHECKED
30
TO FIG.4B

FIG.4A

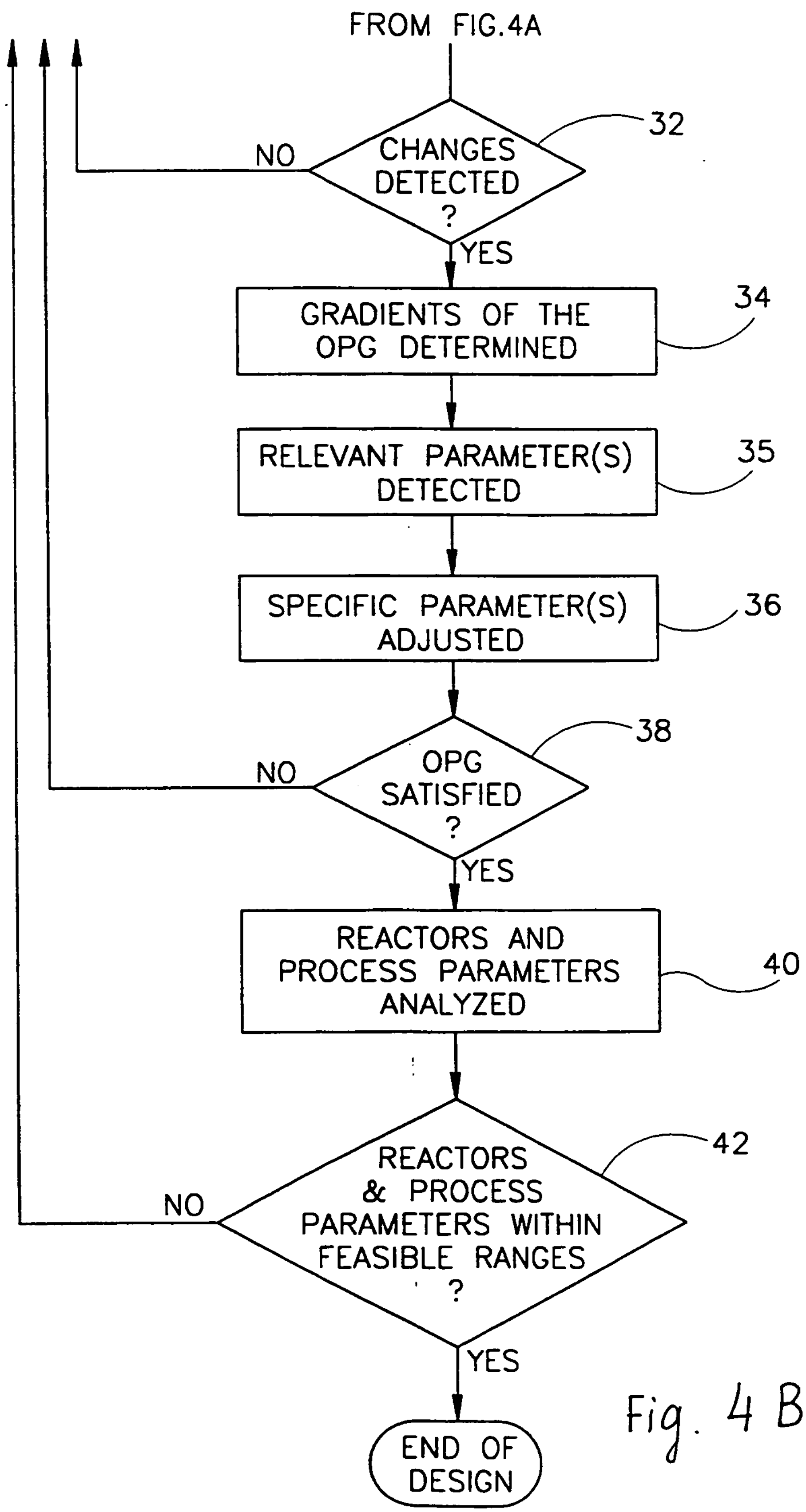

FROM FIG.4A
CHANGES DETECTED ?
32
NO
YES
GRADIENTS OF THE OPG DETERMINED
34
RELEVANT PARAMETER(S) DETECTED
35
SPECIFIC PARAMETER(S) ADJUSTED
36
OPG SATISFIED ?
38
NO
YES
REACTORS AND PROCESS PARAMETERS ANALYZED
40
REACTORS & PROCESS PARAMETERS WITHIN FEASIBLE RANGES ?
42
NO
YES
END OF DESIGN

Fig. 4 B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 99/00119

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G05B13/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 587 897 A (IIDA KAZUHIRO) 24 December 1996 cited in the application see the whole document	1,13,14, 17
A	WO 95 02213 A (SIEMENS AG ;TRESP VOLKER (DE); SCHUERMANN BERND (DE); SCHLANG MART) 19 January 1995 see the whole document	1,13,14, 17
A	WO 96 27824 A (CONTINENTAL CONTROLS INC) 12 September 1996 see page 13, line 3 - page 19, line 15	1,13,14, 17
P,A	US 5 784 596 A (JELENKOVIC PREDRAG ET AL) 21 July 1998 see the whole document	1,13,14, 17

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 June 1999	21/06/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Kelperis, K

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Inte ...onal Application No
PCT/IL 99/00119

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 724 239 A (KANEKO JUNJI) 3 March 1998 see the whole document -----	1,13,14, 17

1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL 99/00119

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5587897 A	24-12-1996	JP 7234862 A	05-09-1995
WO 9502213 A	19-01-1995	EP 0707719 A	24-04-1996
		JP 8512416 T	24-12-1996
		US 5751571 A	12-05-1998
WO 9627824 A	12-09-1996	US 5488561 A	30-01-1996
		AU 2200495 A	23-09-1996
		CA 2214590 A	12-09-1996
		EP 0813699 A	29-12-1997
US 5784596 A	21-07-1998	JP 8111646 A	30-04-1996
US 5724239 A	03-03-1998	JP 8123507 A	17-05-1996